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# Constructal complex-objective optimization for tree-shaped hot water networks over a rectangular area using global optimization method

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ABSTRACT

A tree-shaped hot water network over a rectangular area is investigated in this paper. Based on constructal theory, the total duct wetted surface and duct volume of the network are fixed. To optimize the thermal and flow performances of the networks simultaneously, a complex-objective function, defined as the ratio of dimensionless overall pressure drop to dimensionless farthest user temperature, is chosen as the optimization objective. The complex-objective function is minimized by optimizing the outer and inner insulation radiuses of the insulation radiuses, which is named as the global optimization method in this paper to distinguish the stepwise optimization method used in the previous model. The results show that the optimal constructs of the networks obtained by the minimum dimensionless complex-objective function are different from those obtained by the maximum farthest user temperature. For the volume constraint with the second construction sequence, when the dimensionless insulation volume $\widetilde{V}_2 = 0.3$, the dimensionless farthest user temperature and the dimensionless overall pressure drop based on the minimum complex-objective function are increased by 32.33% and 16.99%, respectively. Therefore, the complex-objective function shows a good compromise between user temperature and pressure drop, and becomes an excellent candidate objective for the performance optimization of the network compared with the single objective of the pressure drop or user temperature.

## 1. Introduction

In 1996, Bejan analyzed the formation and development of the street networks of Rome [1], and proposed the constructal theory [2–28], which was firstly applied into the research of the "volume-point" heat conduction problem to cool electronic devices [29]. Henceforth, many scholars have used this theory to carry out various constructal optimization problems, such as heat conduction optimizations [30–39], simple pure flow system optimizations [40–48], flow system optimizations with various boundary conditions [49–54], civil engineering designs [55–59], cooling channel optimizations [60–65]. Specially, the classical problem in civil engineering is the layout of the tree-shaped hot water networks (TSHWNs). Bejan et al. [55] studied the hot water distribution problem with T-shaped assembly, and obtained the optimal pipe radiuses of the assemblies. Wechsatol et al. [56] assembled the new construct of the TSHWNs by two last order constructs, and got a better thermal-fluid performance than the former two ones. Lorente et al. [57] further discussed the problem mentioned in Ref. [56] based on exergy analysis, and obtained the optimal insulation radii of the hot water pipe. Wechsatol et al. [58] further developed the TSHWNs by using unsymmetrical networks, and the results showed that the one-by-one trees approached the same level of performance of the constructal trees when they became more complex. Feng et al. [59] considered an X-shaped TSHWN, and improved the network's performance greatly compared with the H-shaped TSHWN.

The constructal optimizations mentioned above mainly focused on various single-objective optimizations. Actually, multi-objective optimizations have been the hotspots of the constructal optimizations by taking into account several single objectives simultaneously [66–74]. Lorente et al. [66] studied the thermal resistance of an insulation wall by taking its strength as constraint. This model was further studied in Refs [67,68] by considering thermal resistance, strength and weight simultaneously, and the results in the literatures could be obtained from those of the multi-objective optimizations. Gosselin et al. [69] combined the heat flow and strength of the beam, and optimized the shape of beam with constructal design of multi-objective architecture. Gosselin and da Silva [70] further studied the thermal performance of a nano-fluid flow by taking the power dissipation as constraint, and the particle amounts were optimized for the forced convection and natural convection cases, respectively. Wei et al. [71] considered the thermal

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**Nomenclature**

| | |
|---|---|
| $A$ | Area of the assembly [m$^2$] |
| $A_s$ | Total wetted surface area [m$^2$] |
| $C$ | Complex-objective function [Pa] |
| $f$ | Friction factor |
| $k$ | Thermal conductivity [W K$^{-1}$ m$^{-1}$] |
| $\dot{m}_0$ | Mass flow rate [kg s$^{-1}$] |
| $L_0$ | Length of the elemental volume [m] |
| $L_1$, $L_2$ | Lagrange function |
| $N_0$ | Number of heat loss units |
| $R_i$ | Insulation radius ratio |
| $r_i$ | Inner insulation radius [m] |
| $r_o$ | Outer insulation radius [m] |
| $T_{end}$ | User temperature [K] |
| $T_\infty$ | Ambient temperature [K] |
| $T_0$ | Initial temperature [K] |
| $V_d$ | Total duct volume [m$^3$] |
| $V$ | Thermal insulation volume [m$^3$] |

*Greek symbols*

| | |
|---|---|
| $\Delta P$ | Pressure drop [Pa] |
| $\theta$ | Dimensionless temperature of the farthest user |
| $\lambda$ | Lagrange multiplier |
| $\rho$ | Density of the hot water [kg m$^{-3}$] |

*Subscripts*

| | |
|---|---|
| $m$ | Minimal |
| $opt$ | Optimal |
| 0, 1, 2, … | Elemental volume, first order assembly, second order assembly, … |

*Superscripts*

| | |
|---|---|
| (~) | Dimensionless |

and electromagnetic performances of an electromagnet simultaneously, and optimized the electromagnet's performance by changing its outer radius. Cetkin et al. [72] studied the hybrid grid and tree structures for cooling and mechanical strength. Moreover, the multi-objective constructal optimizations were also applied into the optimizations of steel production processes [73–75].

In Ref. [56], the overall pressure drop (OPD) was minimized first, and the optimal ratio of the internal radiuses of the TSHWN was substituted in the maximization of the dimensionless farthest user temperature (FUT). This was a simple way to calculate the maximum dimensionless FUT. However, the temperature of the farthest user was maximized on the premise that the overall pressure drop was minimized firstly, which sacrificed part of the thermal performance of the TSHWN. Actually, if we optimize the thermal and flow performances (TFPs) of the TSHWNs simultaneously, i.e., by adopting the global optimization method to optimize the TFPs of the TSHWNs, can the

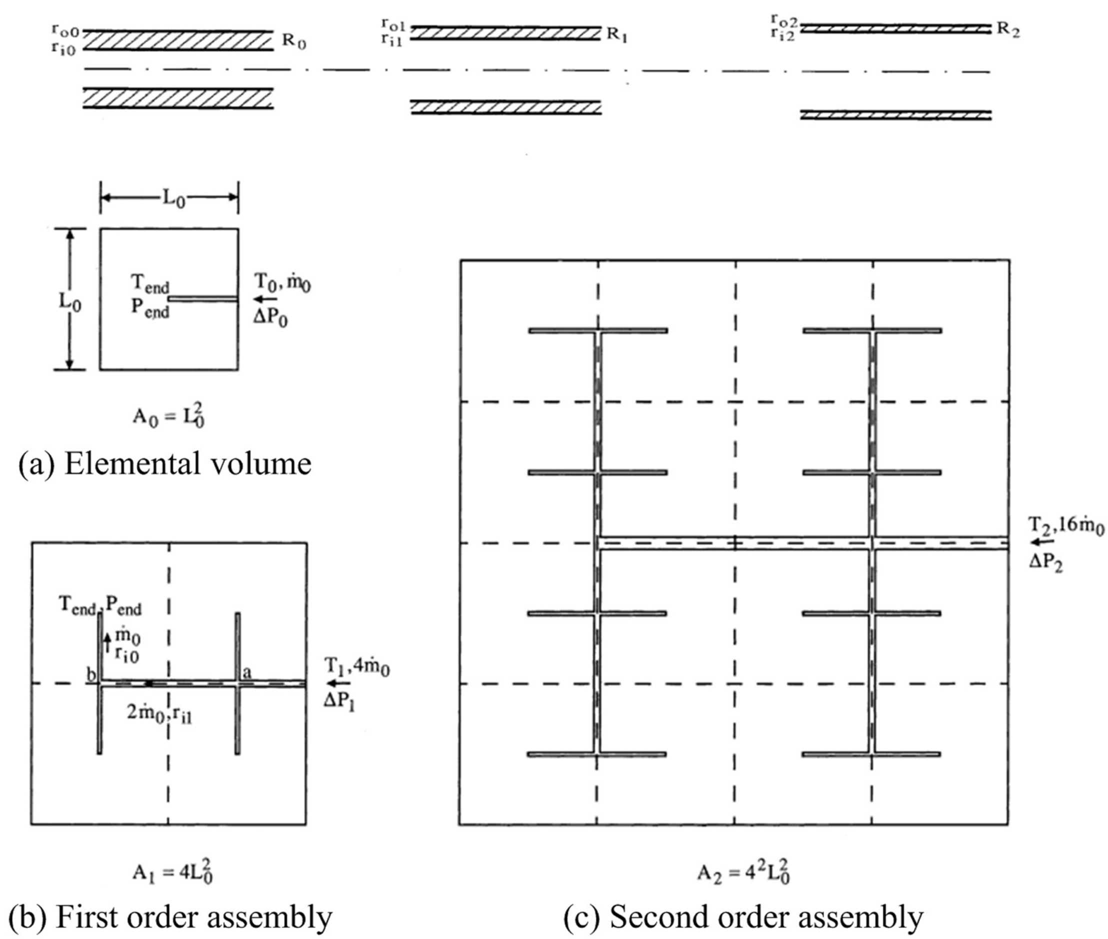


**Fig. 1.** Tree-shaped hot water pipes over a square area with the first construction sequence [56].